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A Review on Plastisphere

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Abstract

Plastic waste contamination has emerged as a growing ecological issue of great significance. Plastic has been found in various environments, including within the human body, creating a growing threat to both ecosystems and people. In the ocean, plastic debris undergoes gradual fragmentation into tiny particles known as microplastics due to the disruption of physical and chemical processes. These microplastics serve as a habitat for diverse microbial communities, such as fungi, diatoms, and bacteria, which form biofilms called plastisphere on the surface of the plastic. In the present review, we summarized the studies related to its formation and things classified in plastisphere. There is also a major distribution found in the plastisphere world. The crucial part to biodegrade the plastics in marine environment is also discussed. The composition of the microorganism community in the plastisphere can be greatly influenced by the depth at which microplastics are found in the ocean and the nutrients present in the surrounding saltwater. There is a rising curiosity surrounding the contribution of bacteria and other microorganisms in breaking down environmentally harmful plastics. The aim is to harness their potential and find effective ways to address the issue of plastic pollution. This includes exploring the possibility of using their abilities to develop improved enzymes for more efficient recycling facilities, landfills, and tackling plastic waste in the oceans. The plastisphere attracts higher creatures such as algae and tiny invertebrates, establishing a complex and dynamic ecosystem on floating plastic particles.

Keywords: Biodegradation, biofilm, community, ecosystems, microorganisms, microplastics, plastisphere

INTRODUCTION

Plastic is an artificial material consisting of polymers, elongated molecular chains derived from petroleum or other origins. Due to its affordability, adaptability, and convenience, it has gained extensive usage across various industries and everyday consumer goods, owing to its versatility and long-lasting nature. Plastic has emerged as the most prevalent type of marine waste. Plastic trash is pervasive in the worldwide ecosystem, with microplastics (MPs) found in the ocean and the marine food chain. Plastic already accounts for 85% of all marine litter, and by 2040, it is expected to nearly triple, contributing 23–37 million metric tonnes of debris to the ocean each year [1]. It is estimated that over 300 million tonnes of plastic are manufactured each year for a variety of applications. Every year, at least 14 million tonnes of plastic enter the ocean, accounting for an astounding 80% of all marine trash discovered in surface waters and deep-sea sediments [2].

Plastics have gained extensive utilization in industrial and everyday contexts because of their exceptional durability, flexibility, resistance to corrosion, and affordability. Plastics' corrosion resilience, on the other hand, makes them harder to disintegrate. Global plastic garbage has surpassed 6.3 billion tonnes in recent years. The predominant types of plastics discovered in the environment are

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carbon-based polymers, namely polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), and polyethylene terephthalate (PET). These five types constitute approximately 80% of global plastic waste. Additionally, polyurethane (PU) and polyamide (PA) plastics are also commonly employed [3]. Plastic pollution has a well-documented impact on animals, including fish, birds, sea turtles, and marine mammals, by ingestion and entanglement. However, studies on the microbial communities associated with plastic are scarce, and our understanding of the effects of this manmade substance and its related ecosystems on the nutrient-poor open ocean is limited. Plastic waste, a relatively new addition to the marine ecology, provides a considerably longer-lasting substrate for bacteria than most natural floating substrates and has been implicated as a vector for the transfer of harmful algal species and persistent organic pollutants (POPs) [3].

About 70–80% of plastic garbage enters the ocean via rivers, scattering across shorelines, surface waters, seafloors, and even isolated places such as open oceans far from land. The ocean currently contains an estimated 51 trillion plastic particles weighing around 236,000 tonnes. Long lifespan and water-repellent surface of plastics encourage microorganism colonisation as well as the movement of hazardous algae species and persistent organic contaminants [3]. According to Frias and Nash, MPs are defined as synthetic solid particles or polymeric matrices, characterized by their regular or irregular shape and varying in size from 1 µm to 5 mm. These particles can originate from either primary manufacturing process, where they are intentionally produced at small dimensions, or secondary sources. It is important to note that MPs are insoluble in water [4].

The term "plastisphere," coined by Zettler et al., refers to a distinct microbial community associated with plastic that differs from its surrounding environment. Two primary methods used to study the plastisphere on marine MPs are environmental sampling and laboratory incubation. However, environmental sampling reports are limited due to the challenges and costs associated with collecting samples, especially in the deep-sea benthic regions. Numerous studies have employed laboratory incubation as a method for investigating the effects of plastic fragments on marine environments. During this process, plastic pieces are incubated in collected saltwater or sediment under controlled laboratory conditions to avoid disturbing the variability of natural environments. Such studies are typically conducted to observe the plastic degradation capabilities of marine microorganisms and the functioning of degradation enzymes, as the controlled environment provides greater stability for these observations. Early plastisphere research relied heavily on microscopy or scanning electron microscopy (SEM) to morphologically distinguish distinct organisms [4]. The small ribosomal subunit *16S gene* (16S rRNA) and the eukaryotic *18S rRNA* gene have been employed for MetabarCoding in most investigations of microbes on the surface of marine MPs using second-generation sequencing technologies, primarily MiSeq Illumina sequencing and 454 pyrosequencing (Roch) [4]. The internal transcribed spacer (ITS) approach is also used to classify fungus in plastisphere. The most widely-utilized genetic barcodes in metabarcoding research for prokaryotes are situated at the high-variable 16S rRNA V4-V5 locus of bacteria, while the V3 locus has also been employed in some early studies [5, 6].

Environmental sampling and laboratory incubation are the two major methodologies for researching the plastisphere on MPs. Environmental sampling is difficult and expensive, especially in the deep ocean, resulting in few reports. Several research have used laboratory incubation to circumvent this. Plastic shards are inserted in collected saltwater or silt in this procedure, and purposefully controlled laboratory settings are produced to replicate natural ecosystems while preserving their variability [7]. Because of the relatively steady settings in the laboratory environment, this type of research is typically well-suited for examining the plastic breakdown capacity of marine microorganisms and the involvement of degradation enzymes. Microscopy or SEM was previously used to morphologically distinguish distinct organisms present in the plastisphere [8]. The *16S rRNA* gene from the small ribosomal subunit and the *18S rRNA* gene from eukaryotes have been used for MetabarCoding in the majority of research investigating microbial communities on the surface of marine MPs. These studies frequently make use of second-generation sequencing technologies, specifically MiSeq Illumina sequencing and 454 pyrosequencing (Roche) [9]. Second-generation sequencing techniques, due to the shorter length of barcode sequences, may often enable identification up to the genus level but have low barcode resolution. Long-read sequencing technologies, such as third-generation sequencing, which can sequence longer parts of the same barcode, should be used to achieve more precise species categorization [10]. The plastisphere is made up of a variety of creatures, including primary producers, heterotrophs, symbionts, and predators, according to microscopic and molecular sequence research. The plastisphere demonstrates a similar relationship between autotrophic organisms and other microbes to the critical significance of interactions between phytoplankton and bacteria in controlling biological cycles and food webs in the oceans.

FORMATION AND COMPOSITION OF PLASTISPHERE

Plastisphere Community

The plastisphere, like other biofilms, is characterized by microbial adherence, the release of extracellular polymeric compounds, and the proliferation of bacteria [11]. Microbes within the plastisphere are commonly observed in the adjacent water bodies or within the sediment layers on the seafloor [12]. The physical attributes of plastic, such as its hydrophobicity, particle shape, roughness, crystallinity, and surface charge, have an impact on the initial choice of bacterial communities during microbial colonization. Subsequently, these pioneering bacteria can influence the selection of subsequent communities within the plastic environment [13]. The primary biofilm layer is established as pioneer bacteria adhere reversibly to the plastic surface, initiating the colonization process. Over time, the surface hydrophobicity of the MPs decreases as these bacteria inhabit and colonize them [14, 15]. Furthermore, these pioneer bacteria can impact the vertical transit of MPs in the water and create a new biological habitat for other microorganisms [16–18]. Moreover, the pioneer bacteria have the capability to secrete exopolysaccharides, which enhance the adhesion of the plastic surface, facilitating the colonization of other microorganisms [19].

The biofilm undergoes further recruitment or loss of species as adhesion to the plastic surface increases. This process ultimately leads to the development of a mature biofilm, which can be attributed to the competition or synergistic effects among different microorganisms [20]. Following this, bacteria can improve irreversible attachment by generating pili, adhesion proteins, and engaging in other active processes such as extracellular polymeric material secretion. These mechanisms lead to the formation of new attachment sites on the plastic surface [21]. Microorganisms are capable of colonizing the surface of MPs within a short span of minutes, whereas the formation of a persistent biofilm requires a significantly longer period of time [22]. Microorganisms follow a specific sequence of colonization on the surface of MPs. Initially, they must overcome the hydrophobic nature of MPs' surfaces to successfully establish their presence [23]. The pioneer colonizers on settling MPs are primarily *Gammaproteobacteria* and *Alphaproteobacteria*, which are among the early microorganisms to establish their presence [22]. Studies have revealed that *Gammaproteobacteria* are the dominant microorganisms in the early biofilms of most polymeric polymer types [12, 21]. During the initial stages of biofilm formation, various other microorganisms such as *Alteromonas, Thalassobius, Neptuniibacter*, *Poseobacter*, and *Phodobacteriaceae* have been identified [24]. Diatoms and cyanobacteria were also observed during the early stages of biofilm development [25, 26].

Over time, *Bacteroidetes*, especially the Flavobacteriaceae family, tend to proliferate in biofilms. This is attributed to their wide dispersal, adaptability, and ability to utilize organic substrates provided by the pioneer colonizers [22, 24]. The bacteria mentioned above are often referred to as secondary colonizers. While the primary biofilm can typically be observed within a week or less, the formation of the secondary biofilm takes several months to occur [12, 26]. In the early phase (30 days) of biofilm formation on PE surfaces, Chen et al. identified Flavobacteriaceae (*Bacteroidia)*, Rhodobacteraceae (*Alphaproteobacteria*), and Microtrichaceae (*Acidimicrobiia*) as the primary colonizers [15]. During the mid-term phase of biofilm development (75 days), the predominant populations gradually transitioned from Flavobacteriaceae and Erythrobacteriaceae to Bacillaceae (*Bacilli*) and Moraxellaceae (*Gammaproteobacteria*). The dominant family of PE colonisers shifted back to

Flavobacteriaceae (*Bacteroidia*) in the later stage of biofilm formation (135 days), with a significant increase in the abundance of these bacteria in Rhodobacteraceae (*Alphaproteobacteria*), Microtrichaceae (*Acidimicrobii*), and Pirellulaceae (*Planctomycetes*).

Plastisphere Distribution

The distribution of different types of MPs varies within the ocean environment. PE and PP are commonly found in higher concentrations within the upper water column where waves and surface currents are more active. On the other hand, PA, PVC, and PET tend to be more prevalent in sediment environments [27]. This connection can be attributed to the physical characteristics of MPs' particles, including their density, surface area, and volume. The microorganisms within the plastisphere exhibit dynamic behavior in response to the condition of the substrate. As a biofilm forms, the physical and chemical properties of MP, such as hydrophobicity, density, specific surface area, roughness, surface micromorphology, and surface charge, undergo changes [6, 23, 28]. These modifications will influence the vertical movement, degradation, and adsorption of MPs to other substances, consequently influencing the biofilm community. Smaller particles tend to disperse to greater depths in the water column, making them less likely to be captured and studied effectively [29]. The relatively slower benthic currents in the water facilitate the transfer of MPs that have settled on the seafloor, causing them to disperse over a wider area of the seafloor [30]. Smaller plastic particles require greater attention because they are exposed to the ocean for a longer period of time, leading to the establishment of more established and stable biofilms on their surfaces. The hydrophobicity of MPs influences their vertical distribution, which reduces as biofilms colonize them, allowing them to sink deeper into the water column [31]. In the deep water, where temperatures are low and sunlight is absent, the microbial populations residing on the surface of MPs undergo changes.

In this environment, the process of biodegradation, carried out by bacteria and other microorganisms, becomes the predominant mechanism for the disintegration of MPs [13]. Alongside the plastic that remains floating on the surface and sinks to the seafloor, a small fraction of plastic waste is carried by waves and deposited on land along the coast [32]. Research has revealed the presence of *Bacteroidetes* and *Proteobacteria* on the surface of plastics, even in deep water environments [21, 33]. Plastic polymer settling in seawater increases microorganisms' access to nutrients on their surfaces, but it also causes environmental stress. Certain MPs have the ability to cling to macro-algae, potentially nourishing reefs or transporting MPs to creatures higher up the food chain. This phenomenon has been noticed off the coast of Qingdao City, China, where a substantial amount of *Ulva prolifera*, a species of macro-algae containing MPs, settles each year. The bacteria that are connected to MPs are also transferred when they are moved to land in this manner [34–36].

Composition of Plastisphere

The plastisphere, the microbial population associated with MPs, can change based on factors such as kind of plastic, location, and environmental conditions.

1. *Bacteria:* In the plastisphere, various bacterial taxa have been found, including but not limited to *Bacteroidetes* (for example, Flavobacteriaceae), *Proteobacteria* (which include *Gammaproteobacteria* and *Alphaproteobacteria*), *Actinobacteria, Firmicutes* and *Cyanobacteria*.
2. *Archaea:* Archaeal populations have also been discovered to be connected with MPs, albeit they have received less attention than bacteria.
3. *Fungi:* Several investigations have found fungal species in the plastisphere, including yeasts and filamentous fungi.
4. *Protists:* The plastisphere has been found to include a variety of protists, including ciliates, amoebae, and flagellates. Algae diatoms and dinoflagellates have also been discovered to be connected with MPs.

The composition of plastisphere can vary based on location and environmental circumstances. Furthermore, fresh research continues to shed light on the diversity and dynamics of the microbial populations of plastisphere.

Classifications of Plastisphere

The term "plastisphere" refers to the communities of MP particles that colonize and interact with them. While no rigorous classification of plastisphere types exists, we can define some typical classes based on specific properties and contexts:

Marine Plastisphere

MPs pose a dual threat to the marine environment. They are often mistaken for plankton by predators, and they can also be ingested by marine organisms, thereby entering the food chain. Additionally, MPs tend to adhere to the surfaces of marine organisms, leading to their deposition and subsequent consumption. In laboratory experiments, it was observed that MP particles got readily adsorbed onto the surface of fucales—a type of marine algae. Moreover, MPs were found in the stomachs and intestines of conch after they consumed algae contaminated with MPs.

Freshwater Plastisphere

Scientists noted that plastics, including MPs (greater than 5 mm) and MPs (5 mm or less), can infiltrate water bodies from a variety of sources. MPs provide a favorable surface for microbial colonization in aquatic settings due to their widespread distribution, abundance, and long-lasting nature. Although the sources of MPs have been discovered, study on their environmental fate and the influence of microorganisms on their fate is ongoing. The interaction of MPs, microbes, and biogeochemical processes is a hotly debated topic. While freshwater ecosystems cover only a small portion of the Earth's surface (0.8%), they are home to a significant number of species, estimated to be around 100,000, out of the total 1.75 million species. However, the extent of the freshwater plastisphere and the microbial species associated with it remains largely unknown. In contrast, in the open ocean, plastics are estimated to comprise approximately 0.01–0.2% of the total microbial biomass [6].

Sediment Plastisphere

The sediment plastisphere refers to the microbial communities that live in and interact with MPs found in marine sediments. Sediments act as a MP reservoir, slowly accumulating over time. Once MPs have settled, they can be hidden inside sediment layers or remain on the surface, offering a home for microorganisms to colonize. After biofouling or assimilation in marine snow or faecal pellets, MPs sink into the sediments and accumulate in benthos and coastal areas, particularly sandy beaches. When compared to neighbouring strata, the microbial communities on the surface of PHBV and PHBV/PO in seabed and dune sand are less diverse. Plastic colonisation is primarily attributed to bacteria in the surrounding sediments, while microorganisms in the water column may also play a significant role in colonising seafloor plastics.

Waste Water Plastisphere

The term 'wastewater plastisphere' refers to microbial populations that colonise and interact with plastic particles in wastewater treatment systems. These systems collect a variety of wastewater, including home, industrial, and agricultural effluents that may contain MPs. Large volumes of plastic can be discharged into aquatic areas by wastewater treatment plants (WWTPs) [37]. According to studies conducted by some scientists in 2017, WWTPs release a substantial number of MP particles into freshwater environments. While these treatment facilities are able to remove a considerable portion of MPs, ranging from 83% to 95%, a noteworthy quantity still persists. For instance, in a German WWTP, the effluent was found to contain approximately 9,103 pieces of MPs per cubic meter [38].

Terrestrial Plastisphere

The term 'terrestrial plastisphere' refers to microbial communities in terrestrial habitats such as soil and land ecosystems that colonise and interact with plastic trash. While the concept of the plastisphere originated in marine studies, new research has expanded the concept to include terrestrial settings. The features of MPs and the surrounding environmental conditions can influence the creation and advancement of a soil plastisphere community. Light, salinity, temperature, nutrient availability, hydrodynamics, and local environmental conditions can play an important role in shaping and changing the microbial communities associated with MPs in aquatic environments. Geographic, spatial, and temporal characteristics, as well as seasonal fluctuations, are known to have a substantial impact on the creation and succession of microbial communities within the plastisphere [39]. Unlike previous research, the presence of plastic trash in soils did not result in a specific enrichment of plastic-degrading bacteria. Instead, it shifted the microbial population towards highly numerous autotrophic bacteria, which are theoretically resistant to hydrophobic environments and play an important role in bio crust formation. Bacterial inoculates from both sites produced extensive biofilms on the surface and within minor cracks on weathered PE chips in a 100-day laboratory incubation investigation. These biofilms had apparent thread-like extracellular polymeric substance (EPS) structures and interconnected networks, which helped them, adhere to the chip's surface [40].

Biodegradation of Plastisphere

Plastics can be recycled by employing chemical processes that transform them into smaller molecules [41]. While chemical processes can enable the recycling of plastics by breaking them down into smaller molecules, the impracticality of large-scale implementation arises due to the demanding reaction conditions and high energy needs involved. Additionally, these processes contribute to significant carbon dioxide emissions and have the potential to generate hazardous chemicals, posing further concerns [33]. Plastic recycling poses significant concerns, and the two most commonly utilized methods are mechanical recycling, which typically yields regranulated plastics, and chemical recycling, which generally produces monomer building blocks [42, 43]. Mechanical recycling is often considered a ‘downcycling’ method that results in the production of lower-quality and lower-value goods from waste materials. Additionally, plastics can be used as a secondary fuel source, but energy recovery from plastic waste can generate harmful and toxic dioxins [44]. Using microorganisms to breakdown MPs increases biodegradability while minimising environmental impact. Flexibility of microorganisms to a variety of settings also promotes optimal MP degradation [45, 46]. Microbial communities linked with plastic waste can not only degrade MPs but also break down organic contaminants that have become adsorbent to them [47, 48]. The laboratory cultivation of microorganisms isolated from the natural environment has been the primary focus of research on the biodegradation of MPs [49]. Usually, these bacteria are obtained from landfills, sewage, mangrove sediment, and waste material, although it is uncommon to directly acquire them from seawater [50, 51].

Biodegradable polymers have been developed for many years as a means of reducing plastic waste, and they are regarded as a feasible alternative in tackling this issue. PLA, PHA, and cellulose are examples of biodegradable plastics. Biodegradable plastics, as opposed to traditional plastics, are produced without the use of oil and have enhanced breakdown qualities. Because biodegradable plastics have only been in use for a short time, there is now a paucity of such plastics in the ocean. As a result, the majority of research on biodegradable plastics involves intentionally introducing them into the marine environment for a set period of time and then analysing the changes in surface biofilms after they are removed [6, 52]. The limited research on degradable plastics in the ocean can be attributed to the fact that a significant portion of these plastics undergo harmless decomposition through composting and other means, resulting in only a small portion reaching the marine environment. However, with the increasing production and utilization of biodegradable plastic products, there is a need for further investigation into their potential risks and fate in aquatic ecosystems [53].

Non-biodegradable plastics are intended to be long-lasting and resistant to both non-living and living degradation processes. However, once released into the environment, persistence of these polymers becomes a big challenge. The bulk of marine MPs are non-biodegradable polymers, such as PS, PP, PE, PVC, and PU. These polymers are generally composed of carbon-carbon (C-C) chains or ether bonds that connect their building units and are typically resistant to microbial digestion, making them difficult to entirely biodegrade [54]. The complex molecular structure of plastic polymers makes microbial breakdown difficult. To facilitate the disintegration process, the plastic must first be broken down into smaller molecular components that cells can easily ingest and metabolise. This is a critical phase before total destruction may occur. Furthermore, the hydrophobic character and high molecular weight of MPs in seawater influence their insolubility. These properties make it even more difficult for microbes to break down MPs quickly [55, 56]. It has been observed that hydrophobic surfaces of polymers can hinder the efficient adsorption and catalytic activity of polymer breakdown enzymes [57, 58].

Microbes can only break down plastics after they have undergone fragmentation caused by ultraviolet (UV) light, hydrolysis, and abrasion. The presence of mycelium, a crucial component, promotes this process. The large plastic molecules are subsequently broken down through hydrolysis and/or oxidative cleavage by enzymes secreted by microorganisms. This breakdown leads to the release of smaller molecules such as zwitterions and monomers. To continue deteriorating plastic, microorganisms oxidize the molecules within their cells. For this reason, the polymer's molecular weight must be sufficiently low to penetrate the cell membrane. These molecules are eventually digested and utilized by other bacteria, resulting in the conversion of complex chemicals into carbon dioxide (CO_2) and water (H_2O) [59]. Most of the research conducted on fungi that can degrade plastic has focused on terrestrial environments rather than marine environments [60, 61]. Fungi have the ability to cling to and breakdown MPs, and the mycelium they produce changes the physical nature of the plastic, making it more biodegradable [62].

By analyzing rRNA genes, the researchers identified hydrocarbon-degrading species within the marine plastisphere. These species include Phormidium, Muricauda, Hyphomonadaceae, and Rhodobacteraceae, which are known to be associated with the breakdown of oil [63, 64]. Research on marine fungi indicated that certain fungi, specifically obligately marine and lignicolous species such as *Corollospora lacera, C. maritima*, and Lulworthia sp., have the ability to utilize hydrocarbons as their exclusive carbon source for growth. These fungi hold the potential to effectively decompose marine MPs [65]. Enzymatic activity is critical in the degradation of MPs by fungi and bacteria. These enzymes, known as plastic degrading enzymes, are classified as extracellular or intracellular enzymes [66, 67]. Certain extracellular enzymes released by pioneer bacteria have the capability to break down the hydrophobic components present on the surface of plastic. This process reduces the hydrophobicity of the plastic, facilitating the colonization of more microorganisms. Over time, internal enzymes further degrade the plastic, transforming it into harmless molecules that re-enter the biogeochemical cycle, such as CO_2, H_2O, and nitrogen gas (N_2) [68]. Fungi are capable of degrading plastics through the utilization of intracellular enzymes, specifically mediated by cytochrome P450 family epoxidases (phase I enzymes) and transferases (phase II enzymes) [62]. Limited studies have been conducted on degrading enzymes within the marine plastisphere in their natural environment, with most discoveries of plastic degrading enzymes occurring in laboratory settings using strains obtained from enriched cultures. It has been observed that individual enzymes, similar to biodegrading bacteria, face challenges in effectively digesting plastic. Figure 1 shows upcycling of MP along with various other strategies to effectively mitigate the MP pollution.

ECOLOGICAL IMPACTS

MPs have arisen as a serious concern in the soil environment, posing hazards to food security and drinking water safety due to bioaccumulation and vertical migration. The fate of MPs in the soil is heavily controlled by soil microorganisms, which can colonise and reside within the "plastisphere." It is critical to collect scientific knowledge about the physicochemical features of the plastisphere in order to gain a full understanding of the environmental impact and build appropriate risk mitigation techniques [39]. MP pollution has been discovered in a variety of habitats, generating serious environmental issues. Because of their persistent nature, these pollutants bioaccumulate as they migrate up the food chain. MPs have a negative impact on ecosystems and many ecological processes. MPs are ingested by creatures, causing them to accumulate in their digestive systems [69]. MPs may be present in tap water. Furthermore, minute plastic fragments have the ability to harbour disease-causing organisms and serve as a method of disease transmission in the environment. MPs can also have an impact on the health of soil organisms and the way soil works.

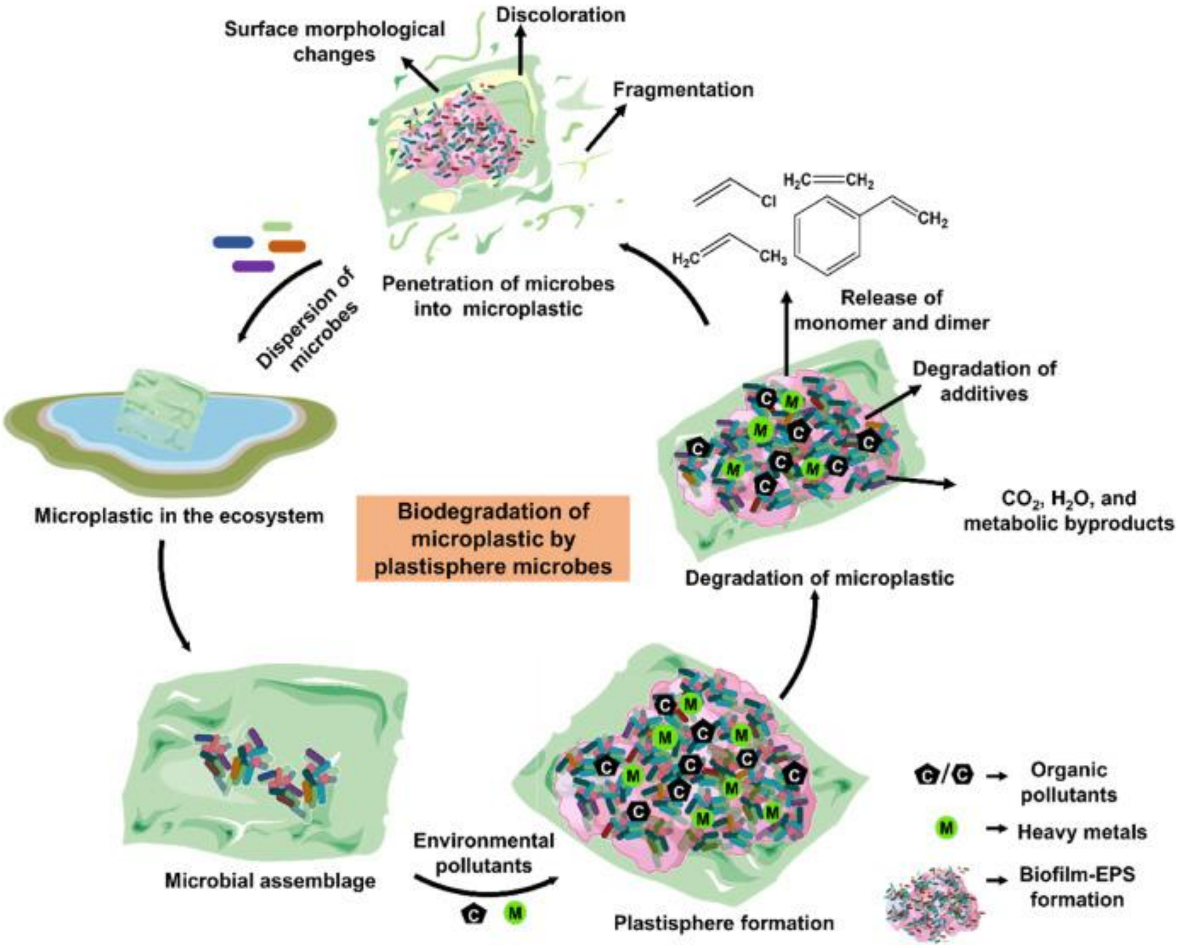

Figure 1. Upcycling of microplastic along with various other strategies to effectively mitigate the microplastic pollution.

MP properties have an indirect impact on possible environmental danger by influencing the composition of viral populations ($p<0.001$). Furthermore, the properties of MPs contributed to the possible environmental danger by changing the composition of bacterial communities [70]. Previous studies [31] have already shown that the functional groups, as well as the chemicals and organic materials adsorbed onto them, significantly impact the properties and behavior of nanoplastics and MPs in aquatic environments [71]. While synthetic fibers are primarily composed of polyester, acrylic, and polyamide, they are released into the environment as primary MPs. It is estimated that approximately 1900 fibers per item can enter aquatic and terrestrial ecosystems through wastewater discharge and the application of sewage sludge during the washing process. As a result, meteorological variables such as wind, tides, surface runoff, and flooding influence the geographical distribution of MPs across distinct environmental compartments [72]. The presence of MPs in plants can result in heightened oxidative stress, reduced root length, decreased chlorophyll content, suppression of seed germination, and other adverse impacts [41].

CONCLUSIONS AND FUTURE DIRECTIONS

The plastisphere is rapidly emerging as a significant and dynamic ecosystem, poised to become one of the most important niches. It not only represents a continually expanding accessible surface, often referred to as the ‘eighth continent’ but also serves as a novel substrate for biofilm formation and biotechnological processes.

Moreover, the plastisphere encompasses a diverse range of species. It is important to note that there is no singular type of plastisphere. Rather, the physical and chemical properties, as well as the shape of the surfaces, vary greatly among different plastic debris, creating distinct and varied biological habitats. Consequently, establishing appropriate categorization and classification systems becomes crucial in understanding and studying the plastisphere.

These essential numerical descriptions will serve as valuable tools in monitoring toxicity, adsorption, conducting microbiological research, and even enhancing the design of new polymer materials for various applications such as electronics, food industry, and biomedicine. In particular, when developing future polymers, it is crucial to consider their long-term effects on the surrounding biota, including the type of plastisphere they may create. This consideration should align with the evolving norms and criteria in order to ensure sustainable and environmental-friendly polymer development.

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